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THERMODYNAMICALLY STABLE CONDUCTING FILMS OF INTERMETALLIC $PtGa_2$ ON GALLIUM ARSENIDE

by

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ABSTRACT

The first epitaxial platinum gallium two ($PtGa_2$) films have been grown on gallium arsenide (GaAs) (100) by co-evaporation of the elements under ultra-high vacuum conditions. An electron beam evaporator and a Knudsen cell were used to produce the platinum and gallium beams, respectively. The resulting films and bulk $PtGa_2$ have been characterized by x-ray diffraction, Auger electron spectroscopy, and x-ray photoelectron spectroscopy. The data confirm the $PtGa_2$ stoichiometry and crystal structure of the films, and demonstrate their chemical stability on GaAs (100). This study supports the contention that $PtGa_2$ can be a suitable, temperature stable contact material on GaAs substrates.

Introduction

The chemistry of metal-semiconductor interfaces ultimately controls the nature of Schottky barrier or Ohmic contact formation [1]. Contact formation on elemental semiconductors is relatively straightforward because of the simplicity of binary phase systems, which have a limited number of reaction products. Transition to compound semiconductor technology has encountered additional difficulty because ternary phase diagrams are significantly more complex and rarely well characterized [2].

In order to employ GaAs based electronic devices for both high reliability and harsh environment applications, chemically stable contacts must be formed at the metal-semiconductor interface. Conventional methods to alleviate temperature induced contact degradation usually involve passivation or interdiffusion barriers [3].

A simple solution to the degradation problem would be the use of an intermetallic compound that is thermodynamically stable to the GaAs surface and that also possesses suitable electronic transport properties [4]. Therefore, the intention of this study was to select and investigate an intermetallic contact on GaAs system chosen from a known ternary phase diagram. The intermetallic compound should exhibit a thermodynamically stable tieline to the GaAs semiconductor. A further consideration is that the intermetallic should be compatible with existing molecular beam epitaxy (MBE) techniques.

On the basis of the Pt-Ga-As ternary phase diagram, as experimentally elucidated by Tsai et. al. [5] and illustrated in Fig. 1, $PtGa_2$ was selected as a candidate for thin film growth on GaAs (100). The existence of the pseudobinary tieline between $PtGa_2$ and GaAs implies that the two bulk compounds do not react with each other in a closed system. $PtGa_2$ is a thermodynamically favored reaction product of the Pt-Ga-As system. Depositing an elemental Pt film on GaAs and then annealing will induce chemical reactions that yield intermetallic compounds of Pt with both Ga and As, accompanied by the subsequent degradation of the interface [5]. Since

$PtGa_2$ is a potential product of such a reaction, it will be much more stable in contact with GaAs than Pt.

Advanced device considerations require that the contacts on GaAs be stable to temperatures in excess of 800°C. The $PtGa_2$ films are stable up to 450°C in air during long-time anneals; further work involving capping or other equivalent procedures is required to determine if stability above 800°C can be achieved.

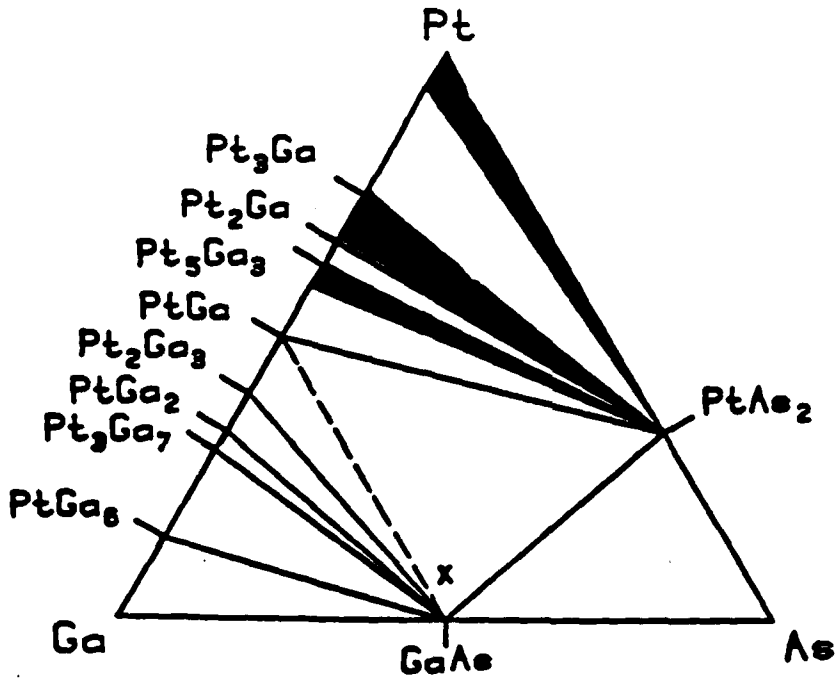

Figure 1. Solidus portion of Pt-Ga-As ternary phase diagram at 25 ° C.

Growth

The $PtGa_2$ films were grown in a MBE chamber with a base pressure of 2 x 10^{-10} torr and a deposition pressure of 4 x 10^{-9} torr. The two inch GaAs wafers were introduced via a cryopumped load lock system and mounted on a modified manipulator equipped with radiative heating elements. The samples were cleaned by heating to a temperature of 550°C under an arsenic overpressure obtained from a Knudsen cell to prevent surface decomposition of the GaAs. The platinum was evaporated using a Varian 3 KW electron beam evaporator and the gallium was obtained from a Knudsen cell constructed of a pyrolytic boron nitride (PBN) crucible with a tantalum heating element. The fluxes of platinum and gallium were initially tuned to the proper stoichiometry. $PtGa_2$ can be visually identified by its characteristic golden color, as $PtGa_2$ is the only Pt-Ga phase that has a band structure similar to that of elemental gold [5,6]. The flux rate from the gallium source was stabilized by temperature control circuits that ensured a constant flux rate for each source power setting. Subsequent depositions have been controlled with a Leybold-Inficon IC-6000 crystal monitor system. To obtain single phase $PtGa_2$ films, the flux ratio of gallium to platinum was adjusted to slightly greater than 2 to 1. Co-evaporation of the $PtGa_2$ proceeded with the sample held at substrate temperatures ranging from near room temperature to over 500°C at an epilayer growth of approximately 5 microns/hour.

Structural and Chemical Characterization

Powder x-ray diffractometry (XRD) patterns of the films were taken on a Philips diffractometer utilizing a Crystal Logic interface to a DEC VAX 11/750 mainframe computer. Diffraction patterns were obtained by accumulation of data for periods of time upwards of twelve hours to achieve an adequate signal to noise ratio. The thin $PtGa_2$ films were annealed in a tube furnace under both nitrogen and air ambients. The film composition and crystallite orientation was subsequently determined by XRD to ascertain the temperature behavior of the epitaxially deposited material. Auger electron spectroscopy (AES) and x-ray photoelectron spectroscopy (XPS) of the $PtGa_2$ thin films and bulk material were performed in a KRATOS XSAM 800 spectrometer that was equipped with a sample treatment chamber (STC), scanning electron microscope (SEM) and ES300 electron spectrometer. In addition, the sample analysis chamber was equipped with a manipulator capable of heating samples up to 450°C while in the analysis position. The base pressure during sample analysis was 2×10^{-10} torr. The samples were subjected to short, low current, rastered 3 KeV ion bombardments until AES revealed no carbon or oxygen contaminants. The samples were then annealed at various temperatures (maximum 450°C) after which AES and XPS data were collected. The XPS data were collected using an aluminum $K\alpha$ excitation source.

Results and Discussion

The resultant films were specular under both optical and SEM examination and golden in appearance. The films were determined to be $PtGa_2$ by the analytical techniques described above. The range of composition of $PtGa_2$ is very narrow, unlike many other intermetallic compounds which have a wide acceptance range of compositions. Figure 2a shows a powder XRD pattern of an oriented $PtGa_2$ (110) film (as seen by the 220 reflection at 43.3°) which was grown on a GaAs (100) substrate at room temperature. Figure 2b shows the XRD pattern obtained after the sample had been annealed at 200°C in a conventional furnace tube. The $PtGa_2$ peaks are virtually unchanged after subsequent annealing to 400°C as shown in figure 2c. The XRD patterns of figures 2a through c consists of peaks solely due to $PtGa_2$ and GaAs. The peaks at 26.0°, 43.3° and 51.0° are the (111), (220) and (311) reflections of $PtGa_2$, respectively. The peak at 66° is the (400) reflection from the (100) GaAs substrate. The XRD pattern showed no observable change from room temperature to annealing temperatures on the order of 450°C. Above 450°C, a small peak around 42.5° was detected. This peak is most probably due to the formation of a Pt_3Ga_7 phase which coexists with the $PtGa_2$ phase. At temperatures above 550°C, a sharp decrease in the intensity of the $PtGa_2$ peaks occurred in conjunction with the appearance of peaks due to PtGa and, most likely, $PtAs_2$.

The electron spectroscopies clearly indicate that the thin film samples have the same stoichiometry and valence band structure as that of a bulk $PtGa_2$ sample. This further served as a verification of the identity and uniformity of the thin $PtGa_2$ films. The stoichiometries were determined by comparisons of the relative peak to peak response of the AES and by the relative peak areas of the XPS data between the thin film samples and a bulk standard. Figure 3 shows the AES signals from a thin film of $PtGa_2$ on GaAs. The electron distribution curves (EDC) determined from the core levels and valence bands are presented in Figs. 4 and 5. In all cases, the thin films produced results that were indistinguishable from the bulk sample.

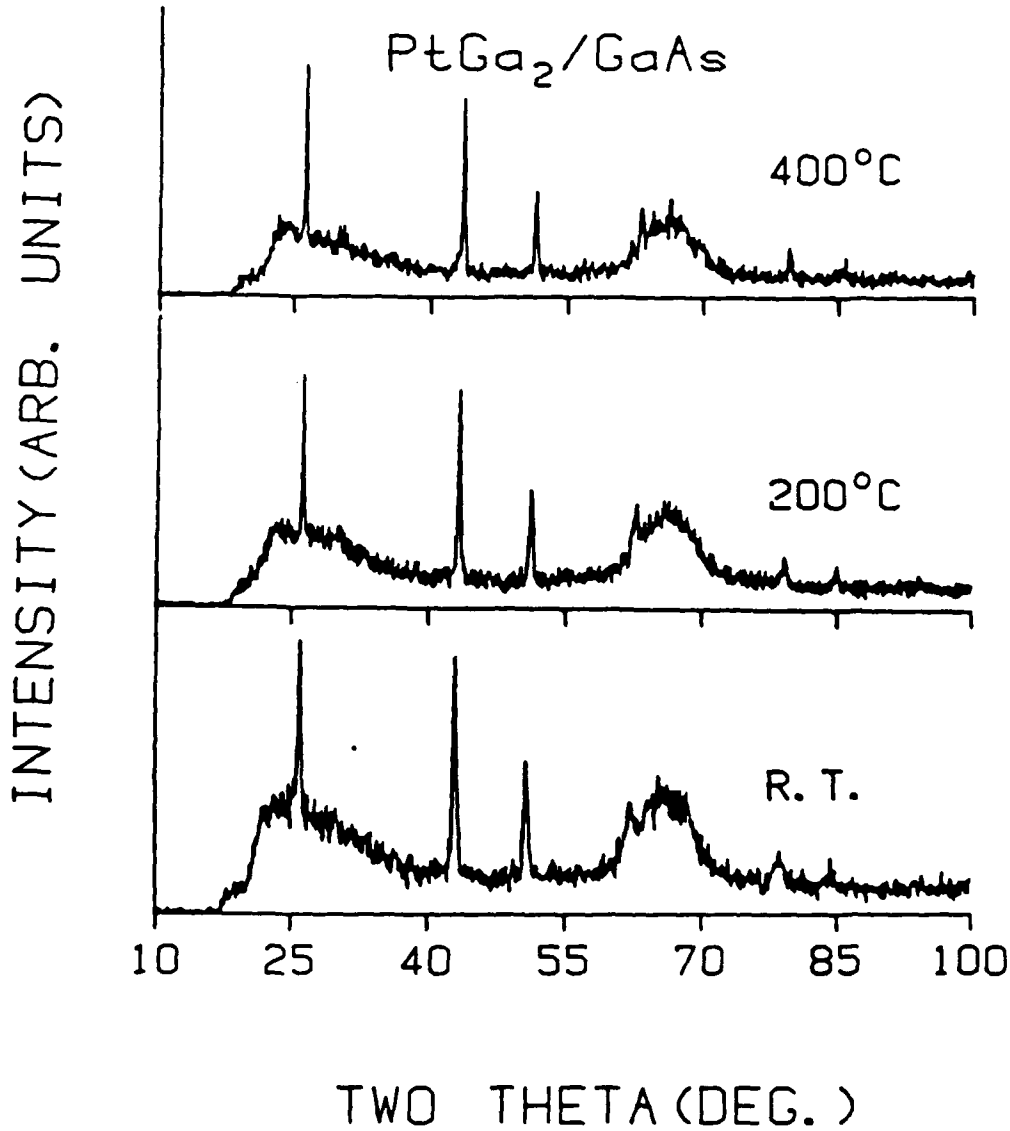

Figure 2. XRD pattern of $PtGa_2$ on (100) GaAs. 2a: room temperature, 2b: annealed at 200°C, 2c: annealed at 400°C. All peaks except the (400) GaAs at 66° correspond to $PtGa_2$.

Conclusions

The successful growth on GaAs (100) of an intentionally designed stable intermetallic thin film that is similar to silicides currently employed in standard silicon processing has been demonstrated. The $PtGa_2$ films are chemically stable on GaAs (100) up to 450°C. $PtGa_2$ shows promise as a suitable contacting material for high reliability applications.

The formation of thermochemically stable $PtGa_2$ epilayers on GaAs will provide an interesting system for the investigation into the nature of Schottky barrier formation and subsequent Fermi level pinning at the interface. We believe that chemically stable $PtGa_2$ intermetallics should eliminate many of the possible chemical factors which influence or effect the phenomenon of Fermi level pinning.

Work in progress to further understand the PtGa family-GaAs system includes temperature-dependent TEM, transport measuremants and the characterization of various intermediate Pt-Ga phases grown by MBE [7].

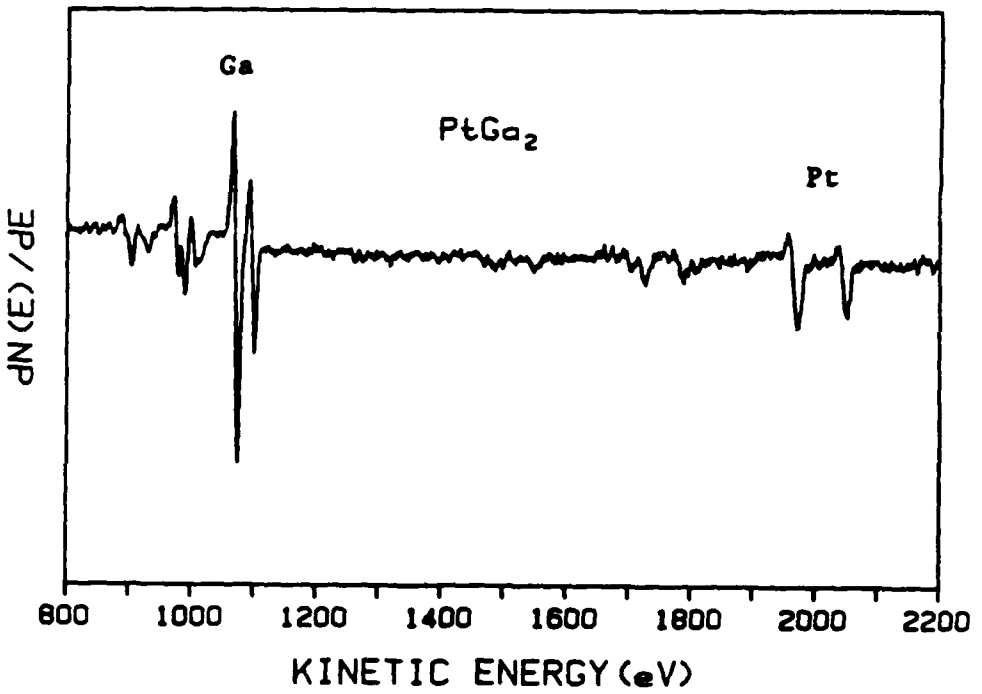

Figure 3. AES spectra of $PtGa_2$ film. The only observable peaks are due to Ga and Pt. The calculated ratio is Ga:Pt 2:1.

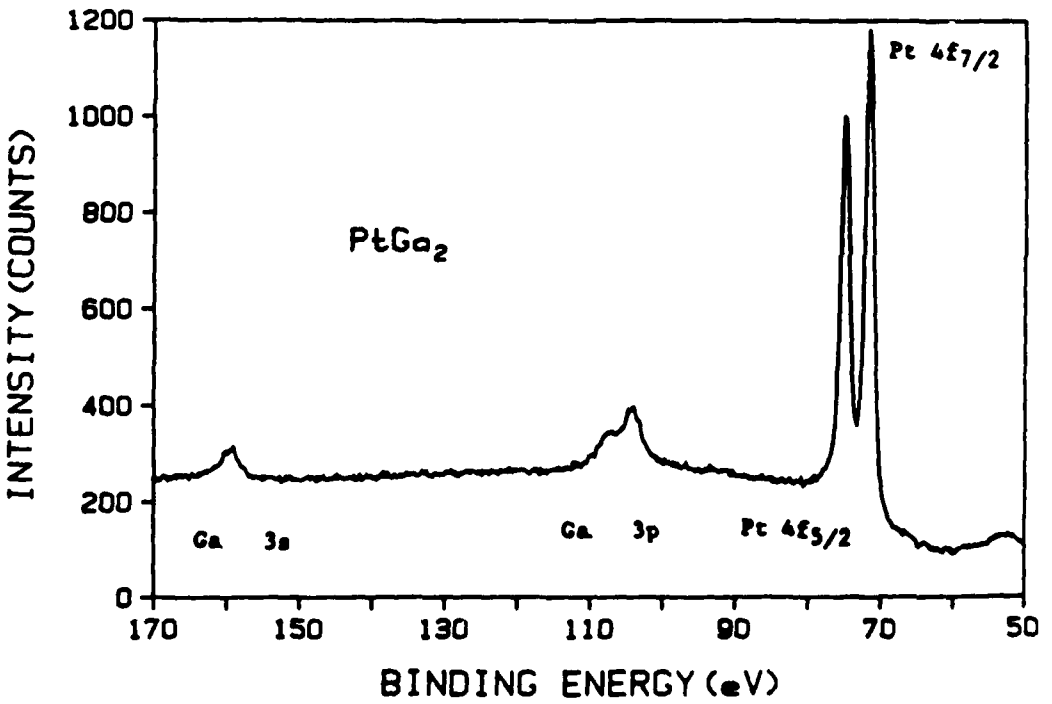

Figure 4. XPS binding energy spectra of $PtGa_2$ film.

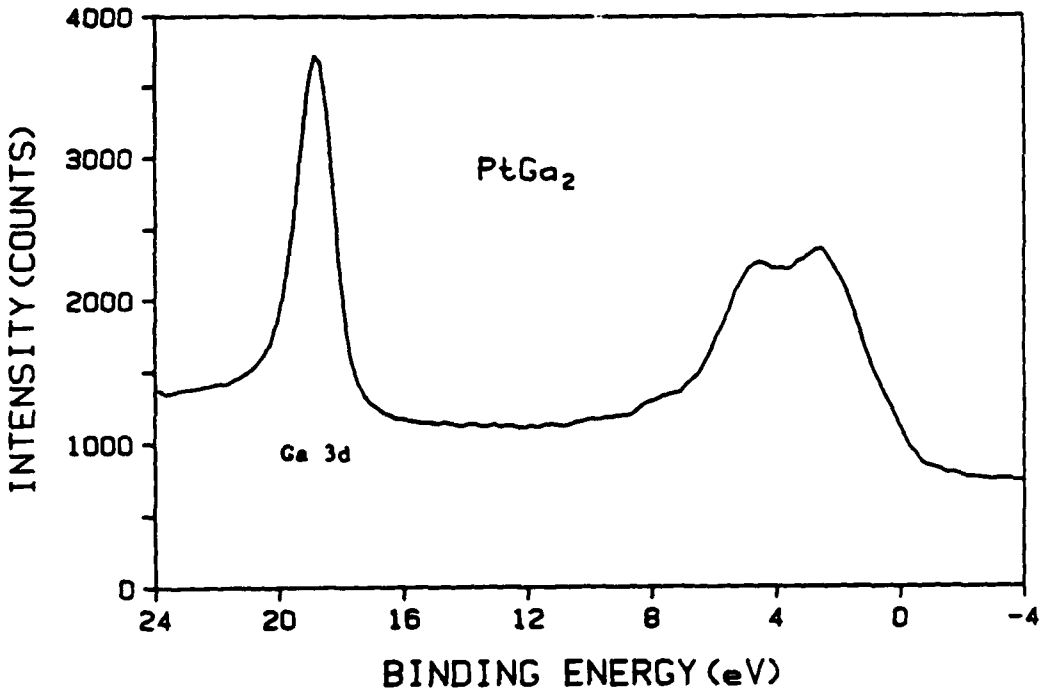

Figure 5. Valance band of $PtGa_2$ film which is identical to bulk $PtGa_2$.

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